ESTIMATION OF EXTERNAL COST ASSOCIATED WITH ELECTRICITY GENERATING OPTIONS IN THAILAND USING SIMPLIFIED METHODOLOGIES

Sameer Shrestha & Thierry Lefevre

ABSTRACT

International Atomic Energy Agency's simplified methodologies are used to estimate external costs for emissions of two types of pollutants, PM10 and SO_2 from two coal fired power plants in Thailand. Both plants show damage cost from chronic mortality is significantly higher than from any other types of health impacts. And, even with the installation of emission control technologies to limit SO_2 and PM10 emissions, the Mae Moh plant (300 MW) results in larger monetary damage than the Thapsake plant (1000MW). Finally, comparing with the detailed analysis results (Impact Pathway Approach), we find that IAEA's simple models are easy to use and provide reliable results using few data.

1 INTRODUCTION

Generation of electricity releases various types of pollutants, which cause damages to a wide range of receptors such as human health, natural ecosystems, crops, and building materials. When the cost of such damages is not accounted in the price of electricity, they are referred as external costs. The estimation of external cost has important use in policy making. A methodology of computing such external cost has been developed through a joint effort between European Community and the United States during the early 1990s, which is known as Impact Pathway Approach (IPA) (ExternE, 1995). This approach quantifies the physical impacts and damage costs associated with airborne emissions and affecting public health, agricultural crops and natural and man made environment. This is a bottom up approach and has been applied successfully in the United States and several European economies. However, this IPA method requires a broad range of data related to various disciplines, such as engineering, meteorology, epidemiology and economic valuation of marketed and non-marketed goods. Developing economies usually lack such detailed database, which hinders them using this detailed methodology.

Recently, International Atomic Energy Agency (IAEA, 1999) introduced simplified methodologies for estimating health impacts from power generation. These methodologies are simple and require minimal calculation effort. Though not completely accurate, they are found to predict health impacts within an acceptable order of magnitude. The degree of accuracy increases with the availability of information. It was observed that deviations in most cases are within a factor of two or so.

In this paper we present outcomes of using IAEA's simplified methodologies on estimating health impact costs for two coal plants in Thailand. The cost of health impacts is estimated for particulate matter and SO_2 emissions from the plants in Mae Moh area (existing) and Thapsake area (planned).

2 IAEA'S SIMPLIFIED METHODOLOGIES

The IAEA's simplified methodologies are developed from the IPA methodology relying upon several approximations, assuming one or more parameters to be constant or uniform throughout the impact domain. Also, these method uses benefit transfer coefficients to transfer the impact estimates from known site (for example, from European sites) to different location (for example, a site in Thailand) for which necessary data are incomplete or not available. The rational for using simplified methodologies are three. First, it permits the user (environmental analyst, policymaker, etc.) to quickly

1

obtain estimates of the impacts of airborne pollution with just a few key parameters. Second, damage estimates can be calculated either for a single isolated source or for multiple sources located in different areas of the impact domain all at once. Third, such estimates serve as a *sanity* check against which the full analysis results may be compared to screen out possible technical and human errors.

The IAEA's simplified methodologies, known as B-GLAD, consist of three different types of models. Among these three models, the most simplified one is the Simple Uniform World Model (SUWM), which requires least amount of data. Two other models Robust Uniform World Model (RUWM) and QUERI are developed relying upon this SUWM model, by adding correction factors to improve its accuracy. Brief descriptions of these models are provided below, detailed discussions are available in IAEA (1999).

2.1 Simple Uniform World Model

The Simple Uniform World Model (SUWM) is derived by simplifying the more detailed approach of IPA's impact assessment function[1] shown below:

$$I = \int_{area} \rho(r) \, F_{er} \, (r, C(Q)) dA \qquad \ldots\ldots\ldots(1)$$

Where, ρ is the receptor density, F_{er} is the exposure response function, C is the incremental change in ambient air concentration at the earth's surface due to emission Q, A is the impact area and r is the source-receptor position vector.

With a number of simplifications on Equation 1, (by assuming one or more parameters are constant or uniform throughout the impact domain) following equation is derived for Simple Uniform World Model (SUWM),

$$I = (\rho.f_{ER}.Q)/k \qquad \ldots\ldots\ldots(2)$$

Where, Q is the emission rate of pollutant, f_{ER} is the exposure response function applied to population at risk, ρ is uniform receptor density throughout impact domain (within 1000 km), k is the depletion velocity, account of pollutant removal from the atmosphere. Followings are the assumptions made to derive above simplified expression:

- The receptors at risk are uniformly distributed about the emission source. This implies that the result is site independent.

- The atmospheric dispersion parameters are treated as constant throughout the impact domain. That is, the dispersion variables are geographically independent of both source and receptor locations.

- All pollutants are assumed to be vertically well mixed across the atmosphere. This implies that the emission source parameters have no significant effect on dispersion.

- The surface removal flux (mass of pollutant depleted per unit horizontal area) is proportional to the local pollutant concentration level (first order rate relationship).

- The exposure-response function is a straight line extending to zero at zero concentration increase. That is, the ER function is linear without a threshold value, which implies that any change in background concentration always has a positive impact on the exposed receptor. The degree of the impact depends solely on the magnitude of the slope of the ER function, which is independent of the absolute value of the ambient concentration.

- The emission or creation rates for a given pollutant are identically equal to its removal rate (chemical transformation plus dry/wet deposition). In other words, the atmospheric concentrations are constant (steady state regime).

The Simple Uniform World Model has two important restrictions due to its assumptions that the impact is insensitive to the immediate population density (or local population density) surrounding the source and to the release parameters, particularly the source stack height. These limitation can

---

[1] For detailed discussion on IPA methodology consult ExternE: Externalities of Energy, Vol. 2: Methodology (ExternE, 1995).

significantly distort results, in particular situations where power plants have smaller stack height, do not produce pollutants like SO_2, which have tendency to produce dominant regional impact.

2.2 Robust Uniform World Model

The Robust Uniform World Model (RUWM) corrects the limitations posed by the SUWM. The RUWM allows using the actual stack height of the source, and improves the accuracy of results. It shall be noted, however, that the results given by the RUWM model are still an approximation to the real impact since the windrose distribution, local and regional population densities are assumed to be uniform about the location of the emission source. It also assumes that the plume rise is driven by buoyancy effects rather than by momentum forces. Despite these simplifications, this method is claimed to be accurate to within a factor of two for many cases (IAEA, 1999).

2.3 QUERI Model

QUERI (QUick Estimation of Respiratory health Impacts) is another computer tool that provides approximate assessment of health effects. QUERI method has also been developed relying upon the SUWM. This method requires knowledge of local and regional population densities, as well as the source stack height. Additionally, this estimate uses a benefit transfer coefficient, which permits transfer of damages from a known site to another location by taking into account differences in local and regional population densities between the reference site and the new location.

2.4 Estimation of Monetary Damage

Estimation for monetary damage for different health impact is calculated using a simplified methodology of benefit transfer method. It involves transferring the cost of other economies (for example, the US or European value) to Thailand value by scaling down using the GDP per capita (purchasing power parity) (Markandya, 1998). This assumes that someone's willingness to pay for better air quality is likely to be lower in a low-income economy. This type of method of transferring values from one economy to another economy assumes that the two risk groups are sufficiently alike. It means two populations under consideration have similar personal preference choices and attitude towards improving air quality standards.

For example, monetary damage cost for Thailand can be estimated as follows, if monetary damage cost for the US is available,

Monetary Damage (Thai) = Monetary Damage (US). (PPP GDP Thai/PPP GDP US)

This relation also assumes that elasticity of willingness to pay (WTP) with respect to real income is one.

3 COAL USE IN THAILAND

Before estimating the health impact costs using the models, a brief background on coal use in Thailand and related environmental issues are presented in this section. Coal and lignite are important energy sources for electricity generation in Thailand. In 1998, coal and lignite supplied 20 percent of the fuel required for power generation. Mae Moh area in the northern Lampang province has the largest deposit of lignite, where 56% of Thailand's proven lignite reserves (2,331 million ton) are found. Lignite in Thailand is characterized by higher sulphur content, which average about 2.6%. The 13 units of power plants (total installed capacity 2,625 MW) in Mae Moh are well known for environmental impacts it produces from SO_2 emission. In 1992, for instance, excessive SO_2 emissions resulted in 1,200 villagers being hospitalized. After that incidence, EGAT began installing FGDs in these power plants. Early this year, EGAT completed installation of FGDs in all ten power plants (remaining three are old units, which are suspended and put on cold standby) and declared the power station as green. With installation of FGDs completed, SO_2 emissions are expected to drop by 90%, reducing SO_2 emissions from 150 ton/year to 15 ton/yr. EGAT has reported that during the cold season of 1999, SO_2 concentration did not increase more than the prescribed value. The hourly

ambient concentrations were in the range of 300-400 µg/m^3 (far below the prescribed value of 1300 µg/m^3).

4 DATA AND ASSUMPTIONS

4.1 Selection of Power Plants

Two coal based power plants are selected for this study to estimate the health impacts from exposure to primary air pollutants, PM and SO$_2$. Brief descriptions of the plants are given below:

Coal Fired Plant in Thapsake

This is one of the two plants that Electricity Generating Authority of Thailand (EGAT) plans to install in Thapsake district, in the south. These thermal power plants will use imported coal (not lignite) and will be built at Thapsake within 2006 to 2007. Each unit will have a capacity of 1000 MW. We calculate physical health impacts from exposure to primary air pollutants, PM and SO$_2$ emission from one unit. The plant is installed with Electro Static Precipitator (ESP) and Flue Gas Desulphurization (FGD).

Lignite Fired Plant in Mae Moh

This is the last unit of the existing thirteen units in the Mae Moh area. The estimates for physical health impacts from exposure to primary air pollutants, PM and SO$_2$ are calculated for one unit of thermal plant in Mae Moh. The plant uses lignite as fuel and is equipped with Electro Static Precipitator (ESP) and Flue Gas Desulphurization (FGD).

Table 1 provides the technical parameters of both plants.

Table 1 Main Parameters of Power Plants

Parameters	Thapsake Plant	Mae Moh Plant
Latitude	11°30'	18°15'
Longitude	99°37'	99°45'
Installed capacity, MW	1000	300
Fuel type	Coal	Lignite
PM10, g/s	27.2	39.4
SO$_2$, g/s	76.4	61.86
Exhaust velocity, m/s	24.1	19.1
Exhaust flow in Nm^3/s	812.5	387
Exhaust gas temperature, ^{o}K	351	353
Stack height, m	200	150
Stack diameter, m	8	5.75
Local population density, per/km^2	28	138
Regional population density, per/km^2	25	25

Figure 1 Location of Power Plants

4.2 Exposure Response Functions

The exposure response functions are taken from the studies by Chestnut et al. (1998) and Pope et al. (1995). These functions relate the incremental change in pollutant concentration level (exposure) to the anticipated damage on particular receptors. Chestnut et al. (1998) provides Thailand specific exposure response functions, which has been estimated based on time series epidemiological study for Bangkok city (Thailand). This study provides exposure response function to compute four types of health impacts, acute mortality (AM), acute respiratory symptom days (ARS), respiratory hospital admissions (RHA) and cardiac hospital admissions (CHA). The exposure response function for chronic mortality (CM) is a transferred value from the US study by Pope et al. (1995).

Table 2 Exposure Response Functions

Impacts	Values
Acute Mortality (AM)[1]	10.5 e-6 YOLL[3]s per person per year per μg/m^3
Chronic Mortality (CM)[2]	2.3 e-4 YOLLs per person per year per μg/m^3
Acute Respiratory Symptom Days (ARS)	3 e-1 days per person per year per μg/m^3
Respiratory Hospital Admission (RHA)	5.7 e-6 per person per year per μg/m^3
Cardiac Hospital Admission (CHA)	5.0 e-6 per person per year per μg/m^3

Source: Chestnut et al. (1998); Pope et al. (1995).

[1] Acute Mortality – deaths, which occur on the same day as, increase in pollution, or very soon thereafter.

[2] Chronic Mortality – deaths, which are the delayed effects of long-term exposure.

[3] YOLL (Year of Life Lost) – cumulative reduction in lifetime expectancy.

4.3 Monetary Damage Values

The monetary unit costs for different health impacts considered in this study are given in Table 3 below. These estimates are obtained by transferring the unit costs in the US and Europe (Chestnut et al., 1998 and ExternE, 1998) using the simplified method described in Markandya (1998).

5

Table 3 Monetary Damage Estimates for Thailand (in 1995 US $)

Impact	Value in US	Value in Europe	Value used for Thailand
Value of life year for acute mortality (AM), YOLL		193,750	75,443
Value of life year for chronic mortality (CM), YOLL		105,400	41,041
Acute respiratory symptom days (ARS), days	12		3
Cardiac Hospital Admission (CHA), cases	14,000		3,788
Respiratory Hospital Admission (RHA), cases	15,000		3,536

Source: IAEA (1999).
GDP (US)=27,600 US$; GDP (European Union)=17,900 US$; GDP (Thailand) = 6,970 US$.

5 RESULTS AND DISCUSSIONS

5.1 Results from the SUWM and the RUWM Models

We estimate five different types of health impacts caused by emission of PM10 and SO_2 for both power plants using the simplified models (the SUWM and the RUWM). As explained earlier, the SUWM model has a most simplified approach to estimate health impacts, it does not treat the local impacts separately (local impact largely depends upon local population density and also on lower stack height). The results obtained with this simplification thus can be less accurate compared with the results obtained from the robust model, RUWM. Unlike the SUWM model, the robust model takes into account of both local population density and actual stack height.

Health impact estimation for a thermal plant in Thapsake site (this plant will use imported coal) is presented in Table 4. Both models provide fairly similar values for all types of health impacts. The values shown are sum of impacts from PM10 and SO_2. This coal based thermal plant emits both PM and SO_2. The plant has a 200m high stack. Higher stack height together with SO_2 emissions has a tendency to increase health impacts in the regional range. This is one of the reasons for close matching between the SUWM and the RUWM results.

Table 4 Health Impacts from the Thapsake Plant (1000 MW, Imported Coal)

Impacts	Unit	SUWM Estimates	RUWM Estimates
Acute Mortality (AM), YOLL	YOLL	2.31	1.89
Chronic Mortality (CM), YOLL	YOLL	35.46	34.67
Acute Respiratory Symptom Days (ARS)	Cases	66,079	64,596
Cardiac Hospital Admission (CHA)	Cases	1.10	1.08
Respiratory Hospital Admission (RHA)	Cases	1.26	1.23

Similar to the Thapsake plant, the Mae Moh plant also illustrates comparable results from the SUWM and RUWM models (see Table 5). The Mae Moh plant, having PM and SO_2 emissions in higher volume and with a higher stack (150 m), has characteristics to give dominant regional impacts than local impact. This is allowing the SUWM model to give results, which agrees with the RUWM results.

Table 5 Health Impacts from the Mae Moh Plant (300 MW, Lignite)

Impacts	Unit	SUWM Estimates	RUWM Estimates
Acute Mortality (AM), YOLL	YOLL	3.01	3.28
Chronic Mortality (CM), YOLL	YOLL	46.21	50.20
Acute Respiratory Symptom Days (ARS)	Cases	86,112	93,544
Cardiac Hospital Admission (CHA)	Cases	1.44	1.56
Respiratory Hospital Admission (RHA)	Cases	1.64	1.78

Figure 2 illustrates comparison of results (for acute mortality) from the SUWM and RUWM models for both power plants. It is interesting to observe here that the SUWM model estimate is lower than the RUWM estimates for Mae Moh, whereas opposite is the case for the coal plant of Thapsake. Thapsake plant is showing this deviation, because, not only this plant has lowest local population density (person/km^2), also its local population density (28 person/km^2) is very close to the regional population density (25 person/km^2) (see Table 1). Whereas the local population density in the Mae Moh area is significantly higher than the regional population density.
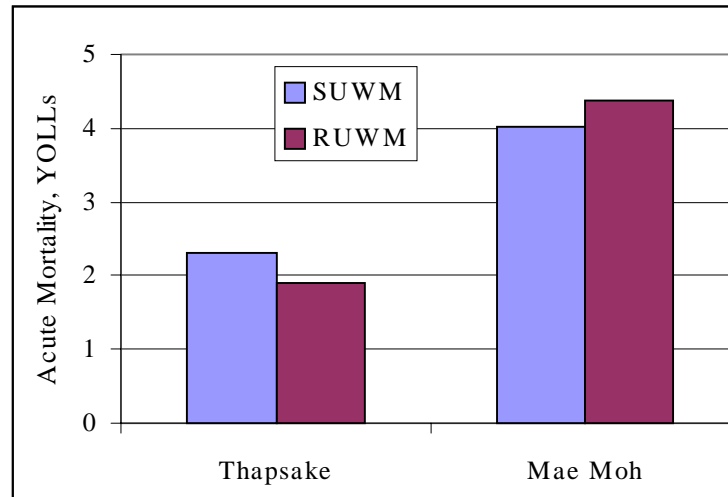

Figure 2 Acute Mortality (AM) for Coal Power Plants in Thailand

5.2 Results from QUERI Model

The QUERI estimate is also based on the SUWM model, but it uses some correction factors to account for changes in stack height and local population density. In addition to that, it uses a benefit transfer coefficient, C_{BT} which allows known impact estimates to be transferred from a reference site in Europe to a different geographical location (say Thapsake) after accounting for changes in receptor density.

The results from QUERI are shown in Table 6. The calculation used real data for plant parameters (e.g. stack height, flow level, etc.) and for location (local population density and regional population density). However, for meteorological data, the default data available in the model are used.

Comparing the QUERI estimates with the RUWM estimates, we observe that for Thapsake plant both values are fairly close, and for the plant in Mae Moh, QUERI estimates are slightly higher than the RUWM. The differences are a result of the benefit transfer coefficients used in the QUERI model.

Table 6 Estimation of Health Impacts from Power Plants in Thailand using QUERI Model

Health Impacts	Thapsake Plant	Mae Moh Plant
Acute Mortality (AM), YOLL	1.55	5.58
Chronic Mortality (CM), YOLL	33.94	85.5
Acute Respiratory Symptom Days (ARS)	44,280	159,310
Cardiac Hospital Admission (CHA)	0.74	3.03
Respiratory Hospital Admission (RHA)	0.84	2.66

5.3 Comparison with Detailed Analysis Results

In this section we examine how the results from the simplified methodologies compare with the results from the detailed approach (IPA). We use the detailed approach values from Thanh (2000), that used impact pathway approach (IPA). This analysis limits the affected area of health impact within the boundary of Thailand and, does not include the affected areas in neighboring economies. Whereas, our estimates from the models (SUWM, RUWM and QUERI) cover all affected areas

within the range of 1000 km from the emission source. Hence, to make these two results comparable, we multiply the results obtained by Thanh (2000) by a factor of 5.79 (the ratio of our affected area within 1000 km radius to the land area of Thailand used by Thanh (2000)). Tables 7 and 8 present the comparisons of results, and show that the results from simplified models are fairly close with the detailed analysis results. This demonstrates that, with a few data, the simplified models of IAEA can estimate the health impacts that do not deviate much from the detailed analysis results (such as IPA). However, among the IAEA's three simplified models, the RUWM model provides more accurate results than the other two.

Table 7 Comparison of Health Impact Estimates, the Thapsake Plant
(1000 MW, Coal)

Impacts	Detailed Method[+]	SUWM	RUWM	QUERI
Acute Mortality (AM), YOLL	1.74	2.31	1.89	1.55
Chronic Mortality (CM), YOLL	NA	35.46	34.67	33.94
Acute Respiratory Symptom Days (ARS)	50,124	66,078	64,596	44,280
Cardiac Hospital Admission (CHA)	0.81	1.10	1.08	0.74
Respiratory Hospital Admission (RHA)	0.93	1.26	1.23	0.84

+ Detailed estimates from Thanh (2000) multiplied by 5.79 to account for all affected areas.

Table 8 Comparison of Health Impacts Estimates, the Mae Moh Plant
(300 MW, Lignite)

Impacts	Detailed Method	SUWM	RUWM	QUERI
Acute Mortality (AM), YOLL	4.17	3.01	3.28	5.58
Chronic Mortality (CM), YOLL	NA	46.21	50.20	85.5
Acute Respiratory Symptom Days (ARS)	119,689	86,111	93,543	159,310
Cardiac Hospital Admission (CHA)	1.97	1.44	1.56	3.03
Respiratory Hospital Admission (RHA)	2.26	1.64	1.78	2.66

5.3 Estimation of Monetary Damage

Monetary damage costs are calculated for all types of health impacts and are shown in Table 7. These costs are annual cost, calculated based on the health impacts from the RUWM model. It should be noted that these costs are not limited to damages within the boundary of Thailand only, but it encompasses total cost for all affected areas. The Mae Moh plant that use lignite exhibits higher damage cost than the Thapsake plant. For both plants under study, the damage cost from chronic mortality (CM) is significantly higher and hence it is a crucial type of health impact.

Table 9 Monetary Damage by Impact Types and Plants, Total Cost (US$, 1995)

Impacts	Unit Cost $	Thapsake Plant	Mae Moh Plant
Acute Mortality (AM), YOLL	75,443	142,488	247453
Chronic Mortality (CM), YOLL	41,041	1,422,749	2,060,338
Acute Respiratory Symptom Days (ARS)	3	193,788	280,632
Cardiac Hospital Admission (CHA)	3,788	4,078	5,906
Respiratory Hospital Admission (RHA)	3,536	4,340	6,285
Total Cost ($)		**1767,442**	**2,600,613**

Among all the monetary damage costs, the cost due to chronic mortality (CM) is significantly high for both plants, which amount more than million US$ per year. The damage costs from acute mortality (AM) and acute respiratory symptom (ARS) days are nearly in same range, coming second after the chronic mortality. The costs related to cardiac hospital admission (CHA) and respiratory hospital admissions (RHA) are lowest among all (see Figure 2).
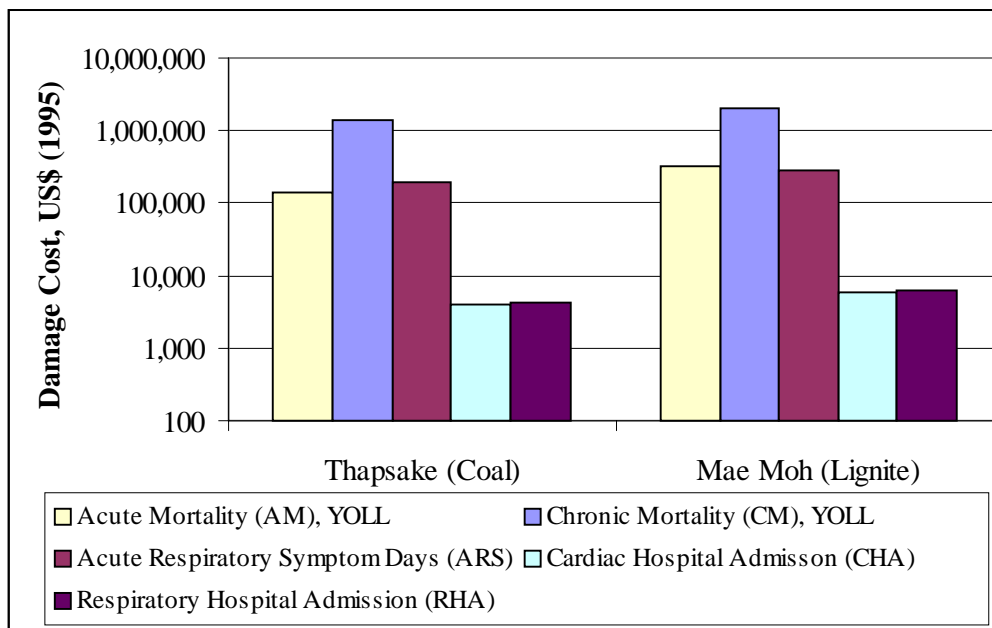
Figure 3 Damage Costs for Power Plants in Thailand (in US$, 1995)

6 CONCLUSIONS

The study shows that the simplified methodologies of IAEA are easy to use, faster and can estimate the external costs of power generation fairly accurately. With few data these models can provide valuable information for policy makers. The models are particularly suitable for developing economies where databases are usually weak.

The study found that for both coal plants in Thailand, the damage cost from chronic mortality (CM) is significantly higher, indicating it is a crucial type of health impact. The damage costs from acute mortality (AM) and acute respiratory symptom (ARS) days are nearly in same range and ranks second after chronic mortality. The costs related to cardiac hospital admission (CHA) and respiratory hospital admissions (RHA) are lowest among all. Even with the installation of emission control technologies (FGD and ESP) to limit SO_2 and PM emissions, a 300 MW plant in Mae Moh results in larger monetary damage than the Thapsake plant. It is because the fuel used in Mae Moh has higher sulphur content and also this area has higher local population density.

Among the models available (SUWM, RUWM and QUERI), RUWM provides best estimates when compared with the detailed analysis results.

REFERENCES

- Chestnut G.L., Ostro D.B, Nuntavarn V., and Smith R.K., 1998. Health Effects of Particulate Matter Air Pollution in Bangkok, Final report for the Pollution Control Department, Royal Thai Government, Bangkok, Thailand.

- ExternE, 1995. Externalities of Energy. Vol.2. Methodology. Published by European Commission, Directorate-General XII, Science Research and Development, L-2920. Luxembourg : EC.

- IAEA, 1999. B-GLAD Model and other materials distributed during IAEA workshop on simplified methodologies, Trieste, July.

- Markandya, A., 1998. A Simplified Methodology for Integrating Externalities into Energy Planning and Comparative Assessment Packages – Methodology and Valuation, IAEA.

- Pope CA III, Thun MJ, Namboodiri MM, Dockery DW, Evans JS, Speizer FE, Heath CW Jr, 1995. Particulate Air Pollution as Predictor of Mortality in a Prospective Study of US Adults, Am J Resp Crit Care Med 151, pp 669-674.

- Thanh B. D. and Lefevre, T., 2000. Assessing Health Impacts of Air Pollution from Electricity Generation: the Case of Thailand, Environmental Impact assessment Review, 20 , pp 137-158.